ASSIMILATION OF REMOTELY SENSED DATA IN A PORTABLE ANALYSIS AND FORECAST SYSTEM

Frank H. Ruggiero
Phillips Laboratory
Hanscom AFB, MA 01731, U.S.A.

Keith D. Sashegyi and Rangarao V. Madala
Naval Research Laboratory
Washington, DC 20375, U.S.A.

ABSTRACT

Previously a portable mesoscale analysis and forecast system was introduced. The system was designed to run on a workstation and provide high resolution short-range 3-12 hour forecasts. In order to meet DoD wartime tactical needs it is important that this system make optimal use of remotely sensed data. Enhancements have been made to the original system to use satellite data in the assimilation of thermodynamic profiles and in an aid in the diabatic initialization of the model. Assimilation of satellite retrieved thermodynamic profiles is accomplished using the coupled approach in which the forecast model provides the first guess for the retrievals. The retrieved profiles are then analyzed using the portable analysis and forecast system's successive corrections objective analysis scheme. This objective analysis is modified to take into account the spatial correlation of the satellite observation error. Results from a case study show the assimilation of the retrievals improves the analyses but has mixed results with the forecasts. The diabatic initialization adds diabatic forcing from stratiform precipitation to a vertical normal-mode initialization. The technique uses satellite estimated precipitation amounts and cloud-top heights with analyzed thermodynamic and kinematic fields to vertically distribute diabatic heating that arises from stratiform precipitation. Simulation experiments reveal the importance of incorporating this heating into the initialization. An adiabatic initialization recovered about 65-75% of the maximum upward vertical motion whereas a diabatic initialization with respect to stratiform precipitation recovered nearly all the original vertical motions. In real data cases, short-term forecasts from a diabatically initialized model, with respect to stratiform precipitation, demonstrate improvement over forecasts from an adiabatically initialized model.

1. INTRODUCTION

Sashegyi et al. (1994) presented a portable analysis and forecast system capable of running on a workstation that provides high resolution short-range 3-12 hour forecasts. Its components include the Bratseth (1986) objective analysis scheme as implemented by Sashegyi et al. (1993) for radiosonde data and Ruggiero et al. (1996a) for surface observations. The Bratseth scheme is iterative, computationally efficient, and will converge to an optimal interpolation solution. The model initialization uses the vertical normal-mode initialization approach as described by Sashegyi and Madala (1993). The initialization also contains the capability to include the diabatic effects of convective precipitation (Harms et al. 1993). The forecast model is the same as used in the Navy Operational Regional Analysis and Prediction System (NORAPS) and has been described by Madala et al, (1987), Hodur (1987), Lieu et al. (1990) and Lieu et al. (1 994). The NORAPS forecast model is a hydrostatic model capable of nesting. Using a simplified version of the model with two nests and running on a RISC- type workstation with a floating point performance of 30

Mflops, Sashegyi etal. (1994) wasable toproduce a12-hforecast inapproximately 3Omins. The portable analysis and forecast system was designed to use an intermittent assimilation strategy since it is computationally less expensive than a 3 or 4-dimensional variational approach. In addition, since it forces all the assimilated data to go through the initialization phase, intermittent assimilation limits the creation of physical imbalances that are possible in nudging (Walko et al. 1989).

In order to be of use to DoD in wartime, the portable analysis and forecast system must be able to work with the data denial that occurs in tactical situations. Given tactical and communication constraints the use of radiosonde and in-situ surface observations will be limited. Reliance will be on data from passive remote sensors that can be down linked to the forward sites. The focus here is to describe the enhancements to the portable analysis and forecast system that make use of certain satellite borne sensors that meet this requirement. In particular, this includes the assimilation of satellite sounder thermodynamic retrievals and the inclusion of a diabatic -initialization with respect to stratiform precipitation.

2. ASSIMILATION OF SATELLITE SOUNDER RETRIEVALS

Traditionally, the standard way of retrieving thermodynamic profiles from satellite sounders are iterative methods that rely on an intelligent choice of a first guess profile. The selection of the first guess is important since the inverse solution of determining atmospheric thermodynamic profiles from satellite measured radiances is non-unique. Recently, much work has been put into using three-dimensional variational analyses to directly assimilate the satellite radiances. Indeed this method has shown great promise (Andersson et al. 1994), however it is computationally expensive to employ and thus not considered here. Here the assimilation of the satellite sounder retrievals is carried out using the coupled approach as described by Lipton and Vender Haar (1990). A schematic outlining how the coupled approach works is given in Figure 1. The process starts with the output of a short-term forecast interpolated to the retrieval locations (unless radiosonde data is available in which case one could use the output from the radiosonde analysis). The retrievals are then calculated and the deviations of the retrievals from the first guess

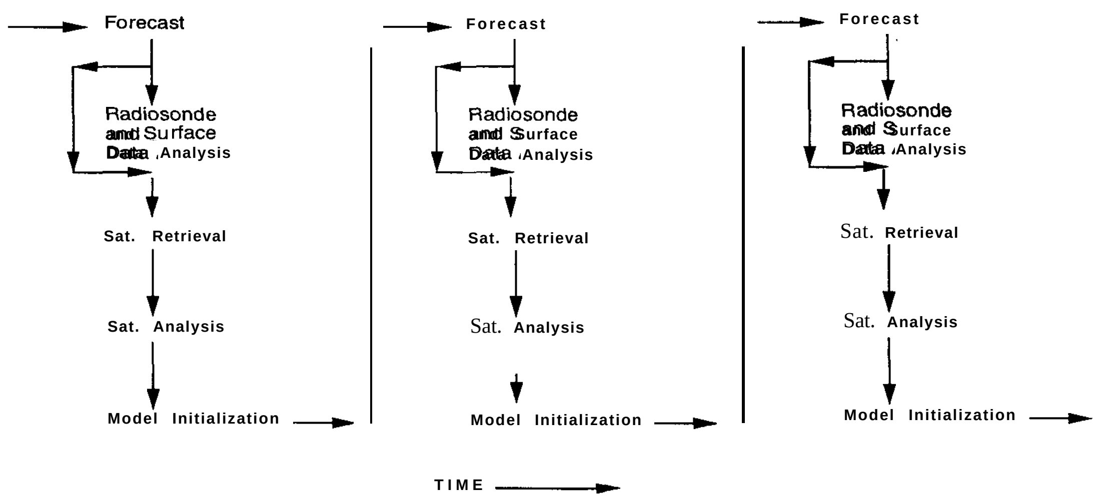

Figure 1. Schematic showing the flow of the model-satellite sounder coupled approach,

profiles are interpolated back to the model grid using the Bratseth objective analysis. The same forecast that provides the first guess for the retrievals is used as the background field for the objective analysis. One important change to the analysis scheme is the inclusion of a spatially correlated portion of the observation error. Previously the observation error was assumed to be to be totally random. When the fields on the model grids are updated an initialization can then be run and the model integrated forward. This cycle can be repeated as often as necessary and data is available.

To examine the utility of the coupled analyses method for assimilating atmospheric temperature and moisture in the portable analysis and forecast system, two experiments were conducted using data from the second 1986 Genesis of Atlantic Lows Experiment (GALE) Intensive Observation Period (IOP). Both experiments started off with a radiosonde and surface data analysis at 1200 UTC 24 January 1986. A control experiment was run by integrating the model forward 24 hours from this point. An assimilation experiment run was done by assimilating -retrievals at 1200, 1500, 1800, 2100 UTC 24 January 1986, and 0000 UTC 25 January 1986 using the coupled procedure as described above. Comparison of the temperature results from the two runs at 1800 UTC 24 January 1986 can be seen in Figure 2 which depicts the root-mean-square (rms) errors of temperatures from an analysis constructed with radiosonde data. The computations of the rms errors are limited to those locations where the retrievals and radiosonde observations are nearly collocated. It can be seen that the analysis resulting from the retrievals improved upon the background field even though the actual retrieval errors were high. The amount of improvement of the analysis over the background field was small. This was due to the high observation error that was ascribed to the retrievals (3.6 K of which 1 K was assumed to be horizontally spatially correlated and the rest random). In addition, one should note that the coupled analysis was improved over the control run. A similar pattern can be seen with relative humidity at the same time in Figure 3. In this case the amount of improvement over the first guess was more significant than it was for temperature. Again the observation error for the humidity retrievals was substantial (15 % horizontal y spatially correlated and 25% random).

Given the relatively modest improvement of the coupled run analyses over the control run, it is not surprising that the forecasts generated from the coupled run do not show a great improvement over the control run forecast. Rms errors of temperature and relative humidity were computed for each forecast run relative to a radiosonde analysis at the radiosonde observation locations at 0600 UTC 24 January 1986. The control run forecast was an 18-h forecast initialized from radiosonde and surface data analyses at 1200 UTC 24 January 1986. The coupled run was also 18-h forecast that used the same initial data as did the control run and that assimilated geostationary sounder data at 3 h intervals from 1200 to 2100 UTC 24 January 1986. The rms errors were similar for the control and coupled runs. For temperature, the values were 1.996 and 2.150 K for the coupled and control runs respectively. For relative humidity, the respective values were 9.346 and 8.618%.

3. DIABATIC INITIALIZATION WITH RESPECT TO STRATIFORM PRECIPITATION

When using frequent intermittent assimilation one has to take care not to continually lose the model generated convergence fields during each analysis and initialization step. One way to “ mitigate this problem is through inclusion of latent heating in the balance to be achieved at initialization. The latent heating is offset by adiabatic cooling from upward vertical motion. As mentioned in Sashegyi et al. (1994) the portable analysis and forecast system already includes a diabatic initialization with respect to convective precipitation. A companion scheme developed by Ruggiero at al. (1996b) performs diabatic initialization with respect to stratiform precipitation. The two schemes work together in that for every grid point at which precipitation has been observed

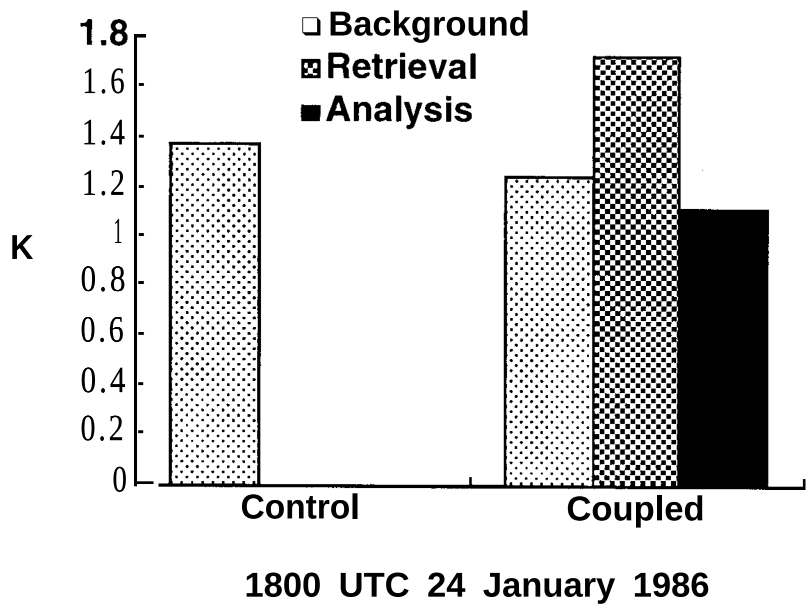

Figure 2. Rms errors of temperature of the control and coupled runs from a radiosonde analysis at locations that have nearly coincident radiosonde soundings and retrievals at 1800 UTC 24 January 1986.

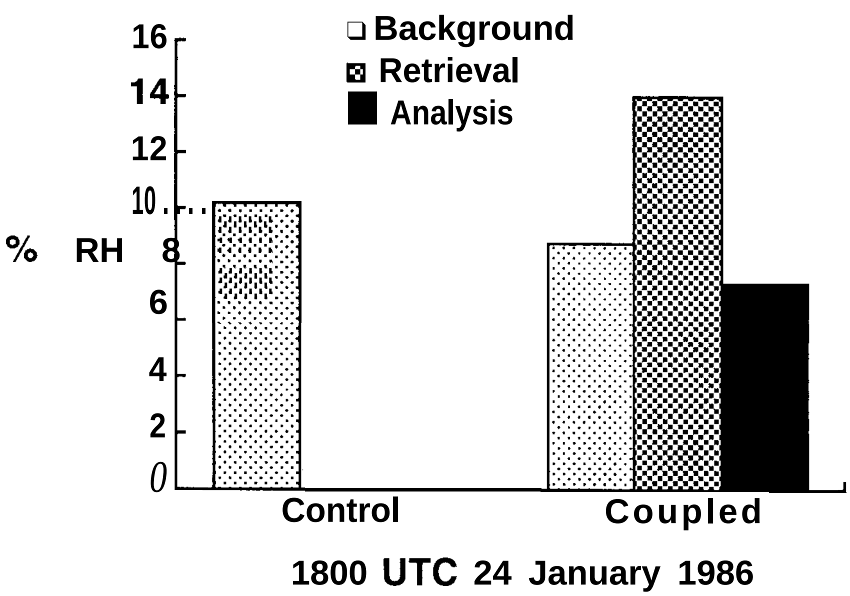

Figure 3. Rms errors of relative humidity of the control and coupled runs from a radiosonde analysis at locations that have nearly coincident radiosonde soundings and retrievals at 1800 UTC 24 January 1986.

during the past three hours, a check of conditional stability is carried out. If the column is conditionally unstable than the convective diabatic initialization of Harms et al. (1993) is used, otherwise the stratiform scheme is used. A detailed description of the diabatic initialization procedure for stratiform precipitation is given in Ruggiero et al. (1996b) and is briefly summarized here. The technique starts off by using the output of three iterations of the adiabatic vertical normal mode initialization. This is done to generate an initial vertical velocity field. The underlying assumption in the Ruggiero et al. (1996b) approach is that the adiabatic initialization will produce the right orientation of the vertical motion fields although the magnitudes are insufficient. The cloud top height for each column is estimated by matching the infrared (11 .24 μm) brightness temperature with that from the initial field. The two model layers below the estimated cloud top height are saturated if not already so. A one-dimensional water vapor convergence calculation is carried out using the kinematic fields from the adiabatic initialization. Water vapor in excess of saturation is condensed out and precipitated down. The total amount of precipitation generated in this manner is added up and compared to the observed precipitation rate. When the generated precipitation matches up with the observed, the latent heat generated at each level is calculated and is added to the physical forcings in the vertical normal-mode initialization. In addition, the moisture fields are adjusted by boosting to 90% the RH at those model levels that are deemed to be producing precipitation. If the RH at those levels already exceed 909" they are left alone.

In order to reveal the importance of including the stratiform precipitation diabatic effects in the initialization, a simulation experiment was run. Using radiosonde and surface data from GALE IOP 2 at 1200 UTC 25 January 1986, the model was integrated forward 12 hours to 0000 UTC 26 January 1986. The output from the model at 0000 UTC 26 January 1986 was considered "truth". At that point two initializations were run using the model output. The first was an adiabatic initialization. The second was diabatic with respect to stratiform precipitation. The input precipitation used for the diabatic initialization was the three hour accumulated stratiform precipitation valid at 0000 UTC 26 January 1986 from the model integration. The cloud top heights were determined by using the highest model level at which supersaturation occurs. Thus the simulations were essentially using perfect input data. Figure 4 shows the 700 mb vertical velocity fields valid at 000026 January 1986 for the model forecast, adiabatic initialization, and diabatic initialization. Comparing the vertical motion between the model forecast and the adiabatic initialization one can see that the process of going through the adiabatic initialization results in the loss of approximately 25-35% of the original maximum vertical motion in the areas of upper Chesapeake Bay and Southern Alabama. However when including the diabatic effects of stratiform precipitation nearly all the original maximum vertical motion is retained in the two areas.

To judge the ability of the diabatic initialization with respect to stratiform precipitation using real data, a second set of experiments was run. In these experiments analyses of radiosonde and surface data were done and the resulting fields were used as input for an adiabatic and diabatic initialization. For the diabatic initialization a 3 hour accumulated precipitation analyses derived from a combination of geostationary satellites and rain gauges was used as the input precipitation field. In evaluating the diabatic initialization it is important to look at precipitation forecasts since the main reason to retain the divergence fields via diabatic initialization is to improve precipitation forecasts. Figure 5 contains the threat scores for the 0.25 cm 3 hour accumulated precipitation contour levels for the forecasts generated from the adiabatic and diabatic initializations at 0000 . UTC 26 January 1986. In general, the threat scores are low but that just points up the current difficulty that exists in forecasting precipitation with a numerical prediction model. At each of the three hour intervals the diabatic initialized forecast produces better results. It should be noted that the diabatic run shows the most improvement over the adiabatic run at earlier times. In the second 6-h period the adiabatic run becomes closer to the diabatic run as the model circulation's spin up.

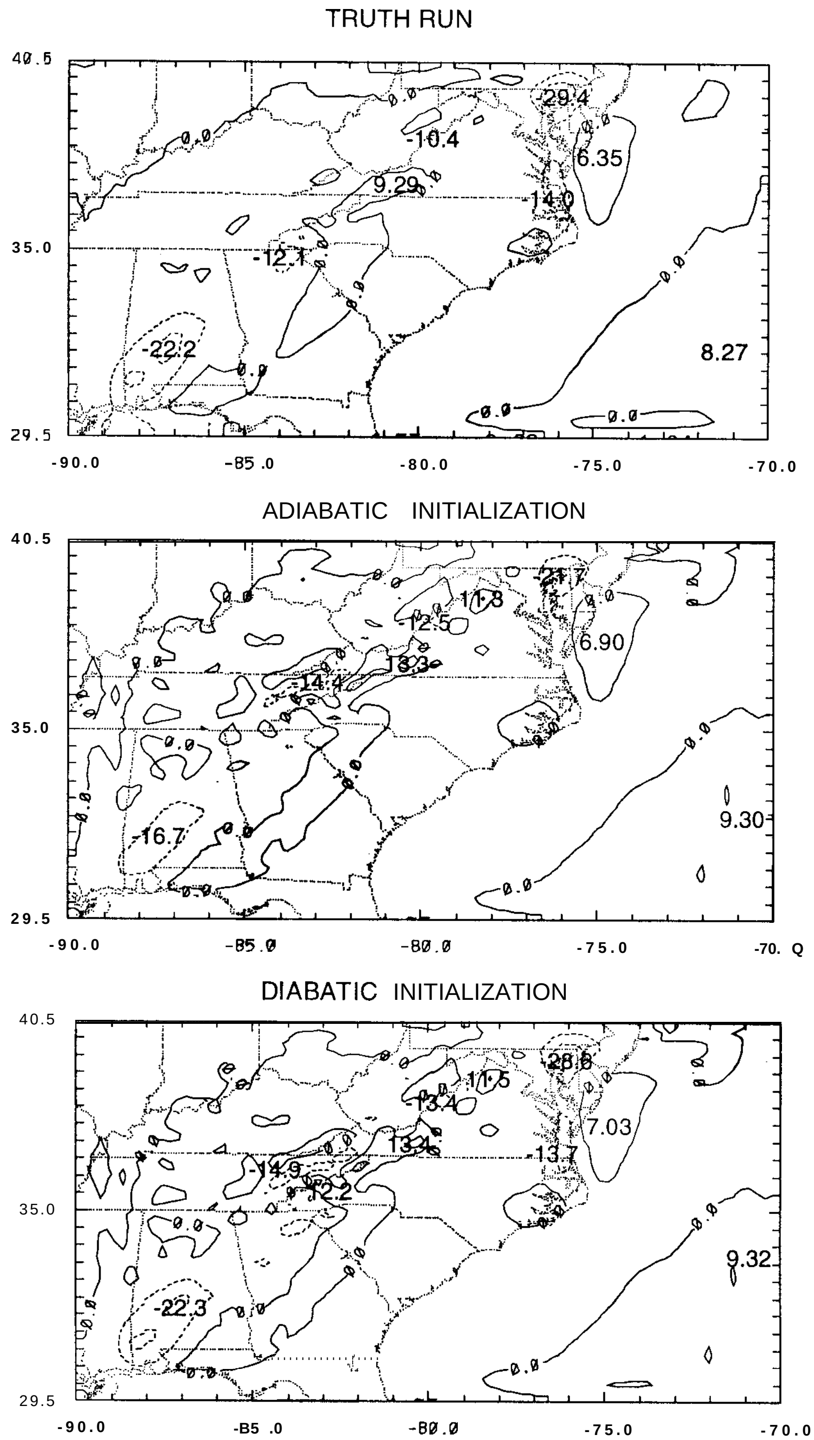

Figure 4. Vertical velocity ($\mu b\ s^{-1}$; contoured every 10 $\mu b\ s^{-1}$; negative contours are dashed) at 700 mb valid at 0000 UTC 26 January 1986 for (a) model output from "truth". (b) adiabatic initialization and (c) diabatic initialization.

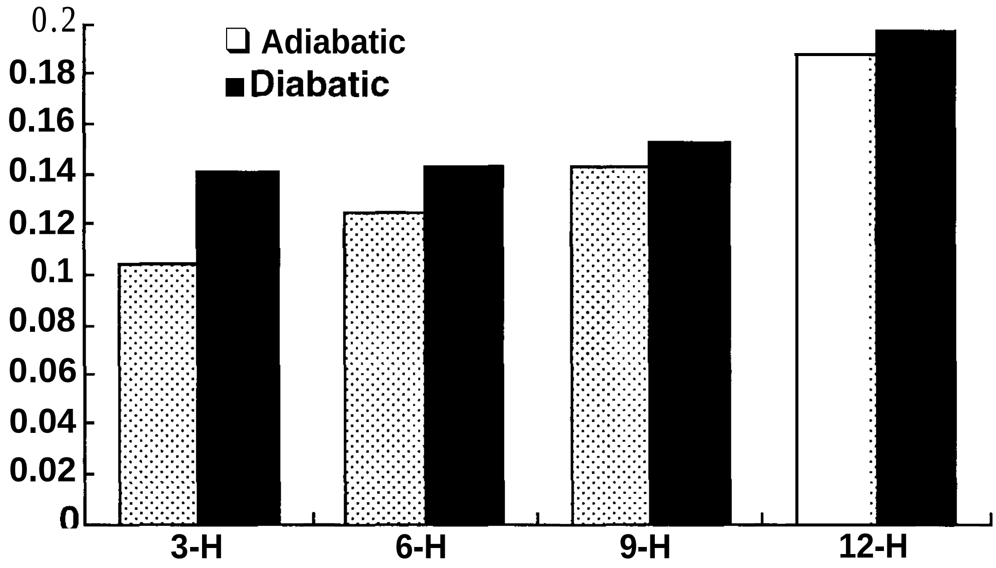

Figure 5. Threat scores at the 0.25-cm contour level for the real data forecasts initialized at 0000 UTC 26 January 1986.

4. CONCLUDING REMARKS

Two major changes have been made to the portable analysis and forecast system described by Sashegyi et al. (1994). One is the modification of the analysis to assimilate satellite retrieved thermodynamic profiles using the coupled approach. The results of tests showed that the assimilation of the geostationary satellite sounder data will improve the temperature and moisture fields during the assimilation period. However these improvements were relatively modest and did not significantly improve the model forecasts. The main reason for the limited success of the assimilation of the retrievals was that the ratio of the observation errors to background field errors did not allow the retrievals to strongly impact the analysis. Both sets of errors were derived from other sources and perhaps are not well suited to be used with either the VAS sounder or the NORAPS model. In hindsight it appears that the observation errors used for the retrievals were generally too high. This can be corrected by gathering error statistics for the coupled procedure retrievals over a large number of cases. In addition, with the new sounder onboard the new generation of GOES (Menzel and Purdom, 1994), the retrievals may be even more accurate than seen here.

The second change to the portable analysis and forecast system is the inclusion of the - diabatic effects of stratiform precipitation in the model initialization. Simulation and real data experiments reveal the importance of including this in the initialization. The results are improved short-term precipitation forecasts. Improvements to this approach can be to use radar reflectivity data (if available) to produce an enhanced precipitation analysis. If three-dimensional radar reflectivity data is available than a more direct method of determining the vertical latent heat distribution is possible. In addition if the time evolution of the precipitation rates are available then perhaps this derivative information can be used to include a time dependent diabatic forcing to the model.

In addition to the above mentioned improvements to the portable analysis and forecast system, work is underway in other areas. Since the next generation of mesoscale models will have the ability to explicitly produce clouds via prognostic variables of cloud liquid and ice water, work is ongoing to come up with initial fields for these variables in order to have accurate short-term forecasts of clouds and precipitation fields. Again the emphasis in this work will focus on determining the required fields using satellite data.

REFERENCES

Andersson, E., J. Pailleux, J.-N. Thépaut, J. R. Eyre, A. P. NcNally, G. A. Kelly, and P. Courtier, 1994: Use of cloud-cleared radiances in three/four dimensional variational data assimilation. *Quart. J. Roy. Meteor. Sot.*, **120, 627-653.**

Bratseth, A. M., 1986: Statistical interpolation by means of successive corrections. *Tellus*, **38A, 439-447.**

Harms, D. E., R. V. Madala, S. Raman, K. D. Sashegyi, 1993: Diabatic initialization tests using the Naval Research Laboratory limited-area numerical weather prediction model, *Mon. Wea. Rev.*, **121,** 3184-3190.

Hodur, R. M., 1987: Evaluation of a regional model with an update cycle. *Mon. Wea. Rev.*, **115, 2707-2718.**

Lieu, C.-S., R. M. Hodur, and R. H. Langland, 1994: Navy Operational Atmospheric Prediction System (NORAPS): A triple nested mesoscale model. Preprints, *Tenth Con. on Numerical Weather Prediction,* Portland Oregon, Amer. Meteor. Sot., 423-425.

Lieu, C.-S., C. H. Wash, S. M. Heikkinen, and R. L. Elsberry, 1990: Numerical studies of cyclogenesis events during the Second Intensive Observation Period (IOP-2) of GALE. *Mon. Wea. Rev.*, **118,** 218-233.

Madala, R. V., S. W. Chang, U. C. Mohanty, S. C. Madan, R. K. Paliwal, V. B. Sarin, T. Holt, and S. Raman, 1987: Description of the Naval Research Laboratory limited area dynamical weather prediction model. NRL Memo. Rep., 5992. Naval Research Laboratory, Washington, D. C., 132 pp. [NTIS A182780.]

Menzel, W. P., and J. F. W. Purdom, 1994: Introducing GOES-I: The first of a new generation of Geostationary Operational Environmental Satellites. *Bull. Amer. Meteor. Sot., 75, 757-781.*

Ruggiero, F. H., K. D. Sashegyi, R. V. Madala, and S. Raman, 1996a: The use of surface observations in four-dimensional data assimilation with a mesoscale model. *Mon. Wea. Rev.*, **124, 1018-1033.**

Ruggiero, F. H., K. D. Sashegyi, R. V. Madala, and S. Raman, 1996b: Diabatic initialization of stratiform precipitation for a mesoscale model. *J. Appl. Meteor.*, 35, 1111-1128.

Sashegyi, K. D., and R. V. Madala, 1993: Application of vertical-mode initialization to a limited-area model in flux form. *Mon. Wea. Rev.*, **121, 207-220.**

Sashegyi, K. D., R. V. Madala, D. E. Harms, and S. Raman, 1994: A numerical weather prediction system for regional and mesoscale forecasting on a high performance workstation. Preprints, *Tenth Conf. on Numerical Weather Prediction*, Portland, OR, Amer. Meteor. Sot., 363-365.

Sashegyi, K. D., D. E. Harms, R. V. Madala, and S. Raman, 1993: Application of the Bratseth scheme for the analysis of GALE data using a mesoscale model. Mon. *Wea. Rev.*, **121,** 2331-2350.

Sashegyi, K. D., R. V. Madala, F. H. Ruggiero, and S. Raman, 1994: A portable system for data assimilation in a limited area model. Preprints, *Battle Atmospherics Conference,* White Sands, NM.

Walko, R. L., C. J. Tremback, and W. R. Cotton, 1989: Assimilation of Doppler radar wind data into a numerical prediction model: A demonstration of certain hazards. Preprints, *24th Conf. on Radar Mete or.,* Tallahassee, FL, Amer. Meteor. Sot., 248-250.